

IONIZATION STRUCTURE OF THE WARM WIND IN NGC 5548

K. C. Steenbrugge^{1,2}, J. S. Kaastra², D. M. Crenshaw³, S. B. Kraemer^{4,5}, N. Arav⁶, I. M. George^{7,8}, D. A. Liedahl⁹, F. B. S. Paerels¹⁰, T. J. Turner^{7,8}, and T. Yaqoob^{8,11}

¹SRON National Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands

²now at Harvard-Smithsonian Center for Astrophysics, 60 Garden street, Cambridge, MA 02138, USA

³Department of Physics and Astronomy, Georgia State University, Astronomy Offices, One Park Place South SE, Suite 700, Atlanta, GA 30303, USA

⁴Catholic University of America, USA

⁵Laboratory for Astronomy and Solar Physics, NASA's Goddard Space Flight Center, Greenbelt, MD 20771, USA

⁶CASA, University of Colorado, 389 UCB, Boulder, CO 80309-0389, USA

⁷Joint Center for Astrophysics, University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA

⁸Exploration of the Universe Division, Code 662, NASA's Goddard Space Flight Center, Greenbelt, MD 20771, USA

⁹Physics Department, Lawrence Livermore National Laboratory, PO Box 808, L-41, Livermore, CA 94550, USA

¹⁰Columbia Astrophysics Laboratory, Columbia University, 538W. 120th Street, New York, NY 10027, USA

¹¹Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218, USA

ABSTRACT

We present the results from our 140 ks *XMM-Newton* and 500 ks *Chandra* observation of NGC 5548. The velocity structure of the X-ray absorber is consistent with the velocity structure measured in the simultaneous UV spectra. In the X-rays we can separate the highest outflow velocity component, -1040 km s^{-1} , from the other velocity components. This velocity component spans at least three orders of magnitude in ionization parameter, producing both highly ionized X-ray absorption lines (Mg XII, Si XIV) and UV absorption lines. A similar conclusion is very probable for the other four velocity components. We show that the lower ionized absorbers are not in pressure equilibrium with the rest of the absorbers. Instead, a model with a continuous distribution of column density versus ionization parameter gives an excellent fit to our data.

Key words: AGN, Seyfert 1, NGC 5548, X-ray spectroscopy.

1. INTRODUCTION

Over half of all Seyfert 1 galaxies exhibit signatures of photoionized outflowing gas in their X-ray and UV spectra. Studying these outflows is important for a better understanding of the enrichment of the Inter Galactic Medium (IGM) as well as the physics of accretion of gas onto a super-massive black hole. Arav et al. (Arav et al.,

2003) and Steenbrugge et al. (Steenbrugge et al., 2003) concluded that there is substantially more lowly ionized gas than has been claimed from previous UV observations. It was concluded that the X-ray and UV warm absorbers are different manifestations of the same phenomenon.

2. OBSERVATION AND DATA REDUCTION

The *XMM-Newton* RGS data was reduced using the standard threads of the SAS version 5.3. For the *Chandra* HETGS data we used the threads in CIAO version 2.2. For the LETGS the 1.5 event file was obtained using CIAO version 2.2, but further data reduction was done using the pipeline described by Kaastra et al. (2002a), which includes an empirical correction for the known wavelength problem in the LETGS and fitted it with responses that include the first 10 positive and negative orders. The data were analyzed using the *spex* package (Kaastra et al., in press).

3. VELOCITY STRUCTURE

The five velocity components measured in the UV (Crenshaw et al., 2003) are listed in Table 1. Each velocity component can have a different ionization parameter and hydrogen column density. Also the variability detected in the ionization parameter is different for the five outflow velocities. Using the MEG, HEG and LETGS

Table 1. The outflow velocity, the velocity broadening and ionization parameter as measured for the five components detected in the UV (Crenshaw et al., 2003).

Outflow km s ⁻¹	broadening km s ⁻¹	U	N _H log m ⁻²
-1040	94	0.03	22.8
-667	18	0.03	22.6
-530	68	0.24	24.3
-336	62	0.03	23.3
-160	90	0.03	22.6

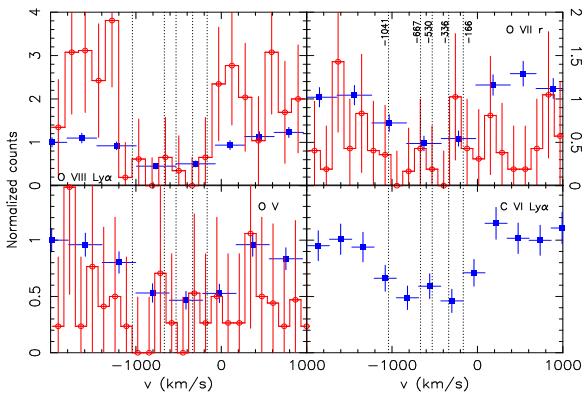


Figure 1. The MEG (open circles) and LETGS (filled squares) data for the O VIII Ly α , O VII resonance, O V and C VI Ly α lines. The dotted lines indicate the outflow velocity measured from UV spectra.

data we were able to resolve the -1040 km s⁻¹ component from the 4 other velocity components in the 6 strongest lines (see Fig 1). This clearly indicates that this velocity component spans an ionization range of at least 3 orders of magnitude, from low ionization UV lines to Si XIV.

4. IONIZATION STRUCTURE

Fig. 2 shows the S-curve, with superimposed the five ionization parameters measured from the RGS spectra. The two lowest ionized components measured from the X-ray spectra cannot be in pressure equilibrium with the higher ionized components. This means that if the absorber is due to clouds in an outflow, they need to be magnetically confined. An equally good fit to the spectra is obtained with a continuous ionization parameter distribution, i.e. an outflow with a density gradient (Steenbrugge et al., 2005). The lowest ionization component measured in the X-rays has a very similar ionization parameter as the ionization parameter measured from UV spectra: $\log \xi_{\text{X-ray}} = -0.03$ versus $\log \xi_{\text{UV}} = 0.05$. However, most of the gas is highly ionized. Assuming a continuous outflowing stream, we derive a power law slope for the column density of 0.4 with ionization parameter.

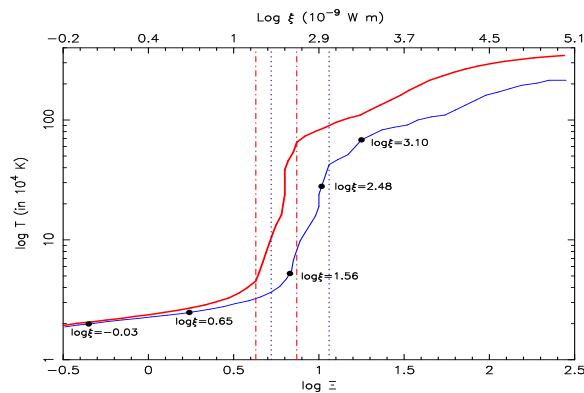


Figure 2. The temperature versus ionization parameter for constant pressure. Points: the ionization parameters measured from the RGS spectra. The ionization parameter ξ for the spectral energy distribution (SED) assumed in the upper curve is indicated on the top x-axis. The dotted and dashed lines indicate the boundaries for the marginally stable branch for the two different SEDs assumed.

5. ACKNOWLEDGEMENTS

SRON National Institute for Space Research is supported financially by NWO, the Netherlands Organization for Scientific Research.

REFERENCES

- Arav, N., Kaastra, J., Steenbrugge, K., et al. 2003, ApJ, 590, 174
- Crenshaw, D. M., Kraemer, S. B., Gabel, J. R., et al. 2003, ApJ, 594, 116
- Kaastra, J. S., Mewe, R., & Raassen, A. J. J. in press, Proc. Symp. New Visions of the X-ray Universe in the XMM-Newton and Chandra era
- Kaastra, J. S., Steenbrugge, K. C., Raassen, A. J. J., et al. 2002a, A&A, 386, 427
- Steenbrugge, K. C., Kaastra, J. S., Crenshaw, D. M., et al. 2005, A&A, 434, 569
- Steenbrugge, K. C., Kaastra, J. S., de Vries, C. P., & Edelson, R. 2003, A&A, 402, 477